TECHNICAL NOTES

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TENSION EXPERIMENTS ON DIAPHRAGM METALS

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Bureau of Standards

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By H. B. Henrickson.

Summary

Strips of german silver, steel, copper, duralumin, nickel and brass were tested in tension in an apparatus in which the change in deflection with time was measured by means of an interferometer. This change in deflection with time caused by the application and removal of a load is defined as "drift" and "recovery," respectively. It was measured in the time interval from approximately 5 seconds to 5 hours after loading.

The data are given in a series of graphs in which the drift and recovery are plotted against time. The proportional drift and recovery in five hours are given for a number of the tests, and in addition are shown graphically for nickel and steel.

Introduction

In determining the fundamental laws of the elastic performance of diaphragm metals, it seems advisable to subject the materials under investigation to stresses which are known in nature and amount in order to obtain definite, known conditions, in contrast with tests on aneroid instruments, in which complex and

*The experiments were performed in 1921 and 1922. Acknowledgment is here made of the financial support of the N.A.C.A. both in the experimental work and in the preparation of this report.

unknown conditions exist, since the problem of the stresses in the diaphragm element has not as yet been solved.

The term "elastic errors" is usually applied to those parts of the elastic performance of pressure elements of pressure-measuring instruments which contribute to the inability of the element to repeat its deflection for a particular load under varying conditions of time and loading. Three errors belonging to this classification are commonly distinguished: (a) Drift is the increase in deflection of the pressure element when it is subjected to a given load for an extended period of time; (b) Hysteresis is the difference in deflection of the pressure element for a given pressure in a pressure-deflection cycle in which the pressure is, for example, increased to a definite value at a given rate and is then decreased to its original value at the same rate; (c) After-effect is the amount by which the pressure element fails to return at once to its initial deflection at the completion of a load cycle. It should be noted that the above are both simple and convenient definitions for use in testing instruments, but that further classification is possible, especially of hysteresis.(Reference 1).

These errors are of considerable importance in all instruments which depend on the action of a spring or diaphragms or a combination of both. The combination of small size and high accuracy under unusual conditions such as is required of most aircraft instruments, makes it desirable to obtain information of the relative behavior of materials in this respect. While springs are a source of elastic errors, the chief source is usually the diaphragm. For this reason, work was initiated mainly on non-ferrous metals which are frequently used as a diaphragm material. Measurements of drift and recovery were made since apparatus which was suitable for measuring small change in length was found to be available at the United States Geological Survey. Although this apparatus was adapted to testing wires, it was found practicable to test in direct tension specimens made up in the form of long, narrow strips. Drift and recovery curves were obtained for strips of german silver, steel, copper, duralumin, nickel and brass. These are presented with observations relating to the experimental technique. It is not the intention to closely analyze the data presented in this report. This is reserved for a future publication, work now being in progress in the Aeronautic Instruments Section of the Bureau of Standards.

Description of Apparatus

The apparatus placed at the disposal of the Bureau of Standards through the courtesy of the Geological Survey was of the light interference type, a diagram of which is shown in Figure 1. The strip for test S, together with two exactly similar strips C (for temperature compensation purposes), were clamped firmly at the top as indicated at A in the figure, and were suspended from a heavy hook. The bottom of the sample strip was fastened to the lower interference mirror M_2 while the bottom of the two compensating strips was attached to the upper mirror M_1. A casing B, was placed around the strips as shown in Figure 1. An outside casing (not shown) was placed around the whole apparatus to protect the latter from air currents and other disturbances.

At the lower end of the strip was hung a scale pan P, on which the weights were placed. The weights including the pan, were lifted on and off by means of a small hydraulic press H, which method caused a minimum of disturbance. Numerous dash pots with freedom of motion in a vertical direction were used to damp out disturbing vibrations.

The scheme of measurement employed a modification of the Fizeau interferometer, the essentials of which are shown in Figure 1. The source of light D, was a helium tube. The rays were rendered parallel by means of lens L_1 and were then passed through the carbon disulphide prism E_1, which separated the light into its various components. Helium gives spectral lines in the red, yellow, blue and violet. The yellow line was used since it was the brightest. The light was focused by means of a lens L_2 upon the edge of total reflection prism E_2, from which it passed through the large lens L_3 and was reflected by means of prism E_3 to the interferometer mirrors M_1 and M_2.

These mirrors were adjusted so that they were nearly parallel and thus caused straight interference bands. The light then retraced its path through prism F_3 and lens L_3, dividing at the second total reflection prism F_2, part of the light being reflected, the remainder missing the edge of the prism and passing through the eyepiece E, in which an image of the interference bands was formed.

As the lower mirror separated from the upper due to the deflection of the sample strip, the black bands crossed the yellow field and could be counted and timed as they passed an index cross-hair. Approximately 5 seconds were usually lost between the application of the load and the commencement of the timing, owing to the fact that it took about this interval of time for the vibrations to die out and let the bands become steady enough to count. This procedure was followed throughout the tests.

An alternative method of following the moving bands with a movable cross-hair, controlled by a micrometer head was tried but was found to be unsatisfactory. It involved more work than the method described above and, moreover, had the disadvantage that 20 seconds usually elapsed after the application of the load before a reading could be obtained.

The passage across the index of one set of bands, a black and yellow was equivalent to one-half wave length separation of the interference mirrors or deflection of the specimen under test. The passage of one-tenth of a set of bands was easily determined. The wave length of the yellow line of helium is 0.588×10^{-3} millimeters, and the precision of measurement of the drift was, therefore, 0.03×10^{-3} millimeters.

The large initial deflection following the application of the load was measured by means of a telescope with a movable cross-hair. The telescope was sighted upon a steel millimeter scale which was attached to the moving element of the sample strip. This elongation was measured with a precision of 0.01 to 0.03 millimeters, which depended somewhat on the sample strip under test. The total elongations were found to vary greatly for a given strip when it was repeatedly subjected to the same load. Results deviated widely from the straight line stress-strain relation which should obtain. This was perhaps due in part to a variation in the amount of slackness in the strips before application of the load.

Data on Specimens

Strips of six metals were tested: german silver, nickel (2 specimens), steel, duralumin, copper and brass. The dimensions, mechanical treatment and chemical analysis for each metal are given in Table I.

TABLE I.

Dimensions, Mechanical Treatment and Chemical Analysis of Strips.

A. Dimensions

Material	Length mm	Width mm	Thickness mm	Area of cross section mm^2
German silver	323.2	6.0	0.14	0.84
Nickel	323.2	5.2	0.15	0.78
Steel	323.2	6.35	0.168	1.07
Duralumin	323.2	6.0	0.12	0.72
Copper	323.2	4.5	0.14	0.63
Brass	323.2	6.0	0.15	0.90

B. Mechanical Treatment

German silver	Cold rolled
Nickel	Cold rolled
Steel	Quenched and tempered
Duralumin	Hard drawn
Copper	Hard drawn
Brass	Hard drawn

C. Chemical Analysis

German silver	Cu 61.3%, Ni 18.35, Zn 20.2, Fe 0.15, Mn----
Nickel	Ni 98.7 , Cu 0.18, Si 0.28, C.078, Mn.08, Fe.66
Steel	Fe 98.40, C 1.25, Mn 0.35, Ni--, Cr--.
Duralumin	Al 94.44, Cu 4.0, Fe 0.68, Mg 0.55, Si.28, Mn<.05
Copper	Cu 99.9, Fe<.01
Brass	Cu 69.3, Zn 30.65, Fe<.05

Experimental Results

Each specimen was subjected to a series of tests in which the elongation and drift were determined upon the application of a load and also upon the removal of the load. Previous to the first test each strip was subjected to about 10-load cycles and then rested 24 hours.

After loading, the rapid part of the drift curve was observed by means of the interferometer and then the elongation was noted by means of the auxiliary scale. The loaded strip was allowed to drift for 4 or 5 hours. The load was then released, the rapid part of the recovery observed and the contraction of the strip noted. The recovery was observed for 3, 4, or 5 hours, depending upon the rate of the recovery and other factors. All the tests were made at room temperatures, which varied from 23° to 31° C.

The drift and recovery for the seven specimens are plotted against time in Figures 2 to 19 inclusive. The applied or removed load is indicated in terms of fiber stress for each curve. The order of making the test is also shown. Both the drift and recovery are shown as commencing at zero time, which is, as has been previously stated, about 5 seconds after the application or removal of the load.

The ordinates of the recovery curves are not true recovery but are the difference between the maximum observed drift and the recovery. Thus, the point at zero time is the last observed value of the drift, and the observed values of recovery are each subtracted from this value before plotting.

A number of facts are brought out by an examination of the drift and recovery curves.

(a) Identical drift curves are, in general, not obtained when repetition of the experiment is made in which the same load is applied. For example, compare curves 2 to 6 for german silver, the curves obtained for 15 kgm per mm² stress for steel and curves 6, 7 and 8 for copper. On the other hand, such good agreement as shown by curves 3, 4 and 5 for the second specimen of nickel should be pointed out. The chief reason for this apparently anomalous behavior lies in the slight variation in the time which elapsed after the application of the load before it was possible to obtain readings. The rate of drift is rapid at this point and even slight variations in time would cause great variation in the total of the drift which was observed.

(b) The statement given under (a) is also true for the recovery curves in which, of course, by recovery is meant the difference between the value of the ordinate at zero time and that at any other time. A further complication exists with these curves, in that the zero drift axis is crossed in some cases, that is, the recovery has exceeded the observed drift, and in other cases the observed recovery is but a fraction of the observed drift. Both of these phenomena are shown by nickel, german silver, steel, copper and brass. It is fair to assume that for these metals, except perhaps copper, the recovery is, to the first order, equivalent to the drift. The explanation, partial at least, of the variation in behavior is that the time elapsing between loading (positive or negative) and the first reading is not necessarily the same for the drift and recovery of a given run, and therefore the total drift and recovery cannot easily be compared.

(c) It should not be assumed that the statements made under (a) and (b) are complete explanations of discrepancies. Efforts at checking the explanation have been made by plotting some of the curves for the same fiber stress in which the drifts at the two-hour point were made to coincide. Thus the common point for the curves was one at which the rate of change of drift was relatively small, such that during small changes in time, such as 5 seconds, insignificant changes in drift would occur. Comparison of the curves thus drawn indicated that other causes of variation also existed.

(d) It is very important to observe that 99% of the total deflection, on the average, had occurred before 5 seconds had elapsed after the application of the load. This fact cannot be easily verified from the curves but an inspection of Table II shows it conclusively.

TABLE II.

Proportional Drift and Recovery in Five Hours

1. German Silver

Stress kgm/mm²	Drift in 5 hr. %	Recovery in 5 hr. %	Stress kgm/mm²	Drift in 5 hr. %	Recovery in 5 hr. %
7.1	0.16	0.16	13.0	0.44	0.30
13.0	0.34	0.18	13.0	0.23	0.18
13.0	0.35	0.30	13.0	0.17	0.28

2. Nickel

Stress kgm/mm²	Drift in 5 hr. %	Recovery in 5 hr. %	Stress kgm/mm²	Drift in 5 hr. %	Recovery in 5 hr. %
3.9(1)	1.2	-	12.0(1)	0.58	0.49
3.9(1)	0.64	1.8	12.0(1)	0.73	0.65
6.1(1)	0.51	0.90	14.2(1)	1.7	0.80
7.7(1)	1.0	0.76	14.2(1)	2.5	0.80
7.7(1)	0.35	0.60	14.2	1.4	1.1
7.7	0.80	1.3	14.2	1.3	0.88
7.7	0.99	1.2	14.2	1.0	0.94
7.7	0.80	1.3	18.0	1.3	0.80
8.6(1)	0.68	0.68	18.0	1.0	0.74
8.6(1)	0.68	0.90	18.0	1.0	0.85
9.8(1)	0.88	0.64	20.7	1.3	0.83
10.3(1)	0.96	-	20.7	1.2	0.83
10.3(1)	1.3	0.81			

3. Steel

Stress kgm/mm²	Drift in 5 hr. %	Recovery in 5 hr. %	Stress kgm/mm²	Drift in 5 hr. %	Recovery in 5 hr. %
5.6	0.28	0.36	15.0	1.1	0.87
5.6	0.36	0.36	15.0	1.1	0.75
10.3	0.20	0.23	15.0	2.6	0.75
10.3	0.35	0.35	15.0	7.4	0.39
10.3	0.20	0.29	15.0	1.5	0.50
10.3	0.30	0.34	15.0	2.2	0.63
15.0	2.0	-	19.7	2.3	0.86
15.0	0.98	1.3	19.7	1.7	0.78
15.0	0.79	1.0	19.7	4.2	0.78
15.0	1.5	0.88	19.7	3.1	0.79
15.0	-	1.0	19.7	3.7	0.82

(1) Indicates that the results were obtained on the first specimen.

Table II (Cont.)

Proportional Drift and Recovery in Five Hours

Stress kgm/mm²	Drift in 5 hr. %	Recovery in 5 hr. %	Stress kgm/mm²	Drift in 5 hr. %	Recovery in 5 hr. %
		4. Duralumin			
3.2	2.3	1.5	4.9	2.0	1.8
4.1	1.8	1.6	8.3	1.7	1.6
		5. Copper			
2.6	3.2	4.8	4.4	4.7	5.0
2.9	3.3	4.5	6.7	3.3	–
3.2	6.1	4.5	6.7	2.6	–
3.6	4.0	4.4	6.7	3.9	0.54
		6. Brass			
6.6	–	0.16	12.2	0.15	0.15
6.6	3.4	0.28	12.2	0.89	0.15
6.6	15.8	x	12.2	1.0	0.15
6.6	7.1	x			

x – Recovery negligible.

(e) Attention is directed to the similar form of the drift curves for all the metals. This corresponds also to results obtained on instruments such as aneroid barometers.

Proportional Drift

The proportional drift and recovery for five hours are given in per cent in Table II for the majority of the tests made on each of the specimens. This is defined as the drift, or recovery, divided by the total elongation (positive or negative). The drift and recovery were obtained from the curves extended when necessary and feasible, shown in Figures 2 to 19 inclusive.

An examination of the elongations observed in the manner previously described showed them to be erratic. An attempt was made to obtain a value of the elongation corresponding to a given fiber stress for each specimen by plotting the observations against fiber stress and drawing the best straight line through them, but the line did not pass through the origin and computation of the slope indicated excessive deviations from the accepted values of the modulus of elasticity. Since it is easily possible that kinks or curves in the strips could affect the observed values of the elongation and further, since comparative values of the drift and recovery were desired, free as possible from outside sources of error, the use of these values was discarded. An average value of the modulus of elasticity was used in order to compute the elongation corresponding to each fiber stress.

The proportional drift for duralumin, copper and brass are larger on the average then for the other three metals. It is not believed that much significance can be attached to the large values of the proportional drift given for brass stressed at 6.6 kgm per mm^2, nor can too much dependence be placed on the uniformly low values of the recovery for this metal.

The results for nickel and steel are plotted in Figure 20, showing separately the drift and recovery.

The scattering of the points on the curve for nickel shown in Figure 11 gives an idea of the accuracy as affected by all causes and therefore of the difficulty in obtaining good observations. It is indicated that the proportional per cent drift of nickel is below 1.0 per cent for fiber stresses below 20 kgm per mm^2.

The values of the per cent drift and recovery for steel show relatively low values below fiber stresses of 10 kgm per mm^2 as has been found true by experience in instrument work. The rise in the value of the per cent drift for fiber stresses just above 10 kgm per mm^2 is peculiar and is not believed to be a property of the steel specimen, at least at such low values of the fiber stress.

Reference

1. Keulegan, G. H. : Statical Hysteresis in the Flexure of Bars. Bureau of Standards Technologic Paper No. 332, 1926.

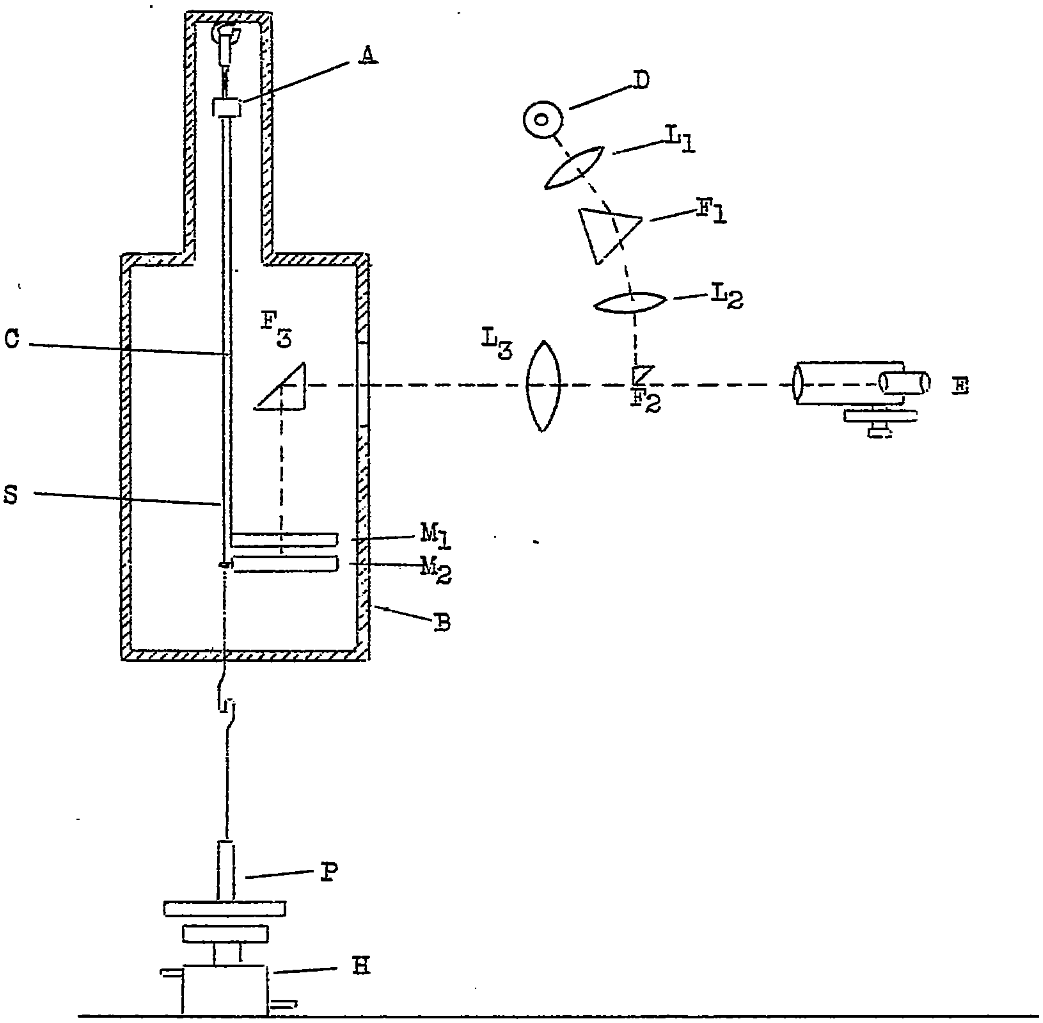


Fig.1

Order of Test	Stress kgm/mm^2
1	7.1
2	13.0
3	"
4	"
5	"
6	"

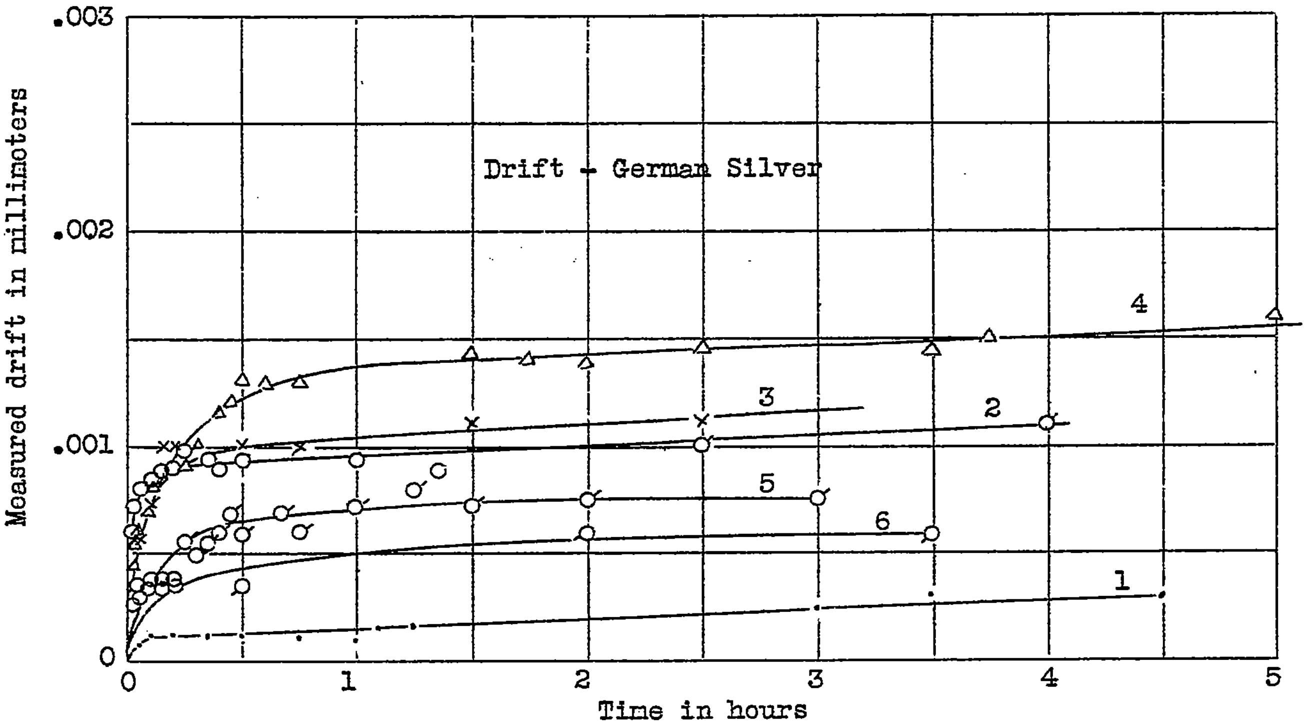


Fig.2

Order of Test	Stress kgm/mm^2
1	7.1
2	13.0
3	"
4	"
5	"
6	"

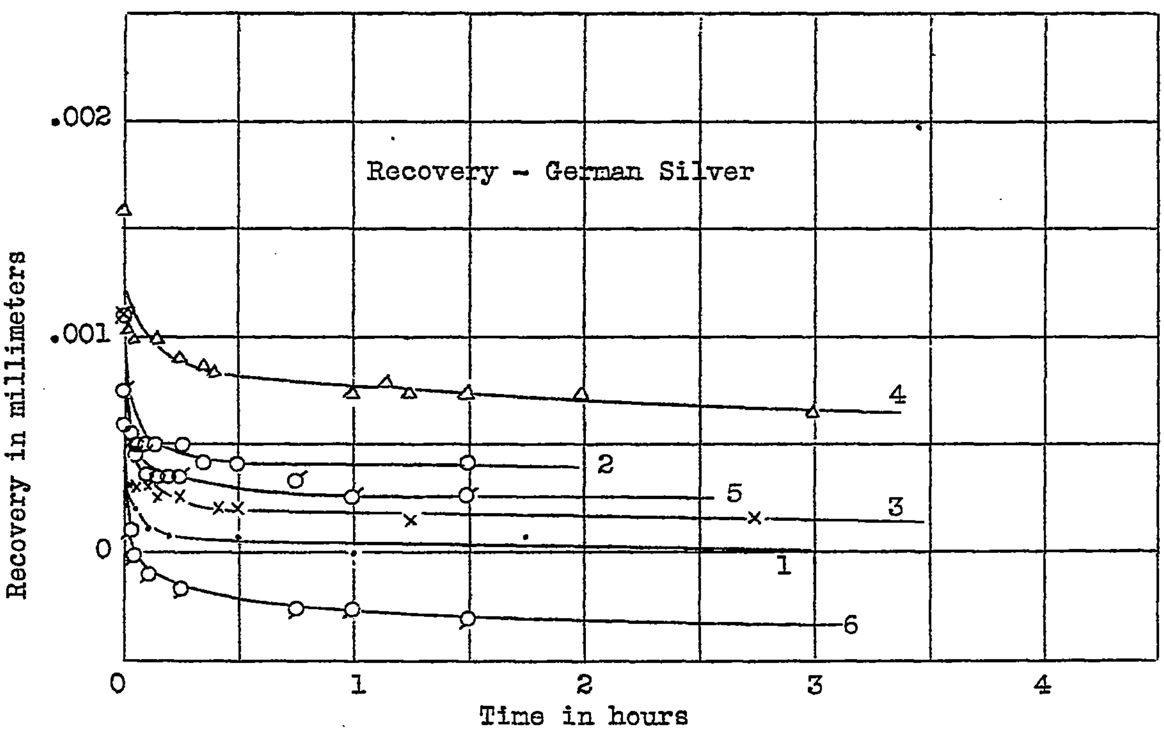
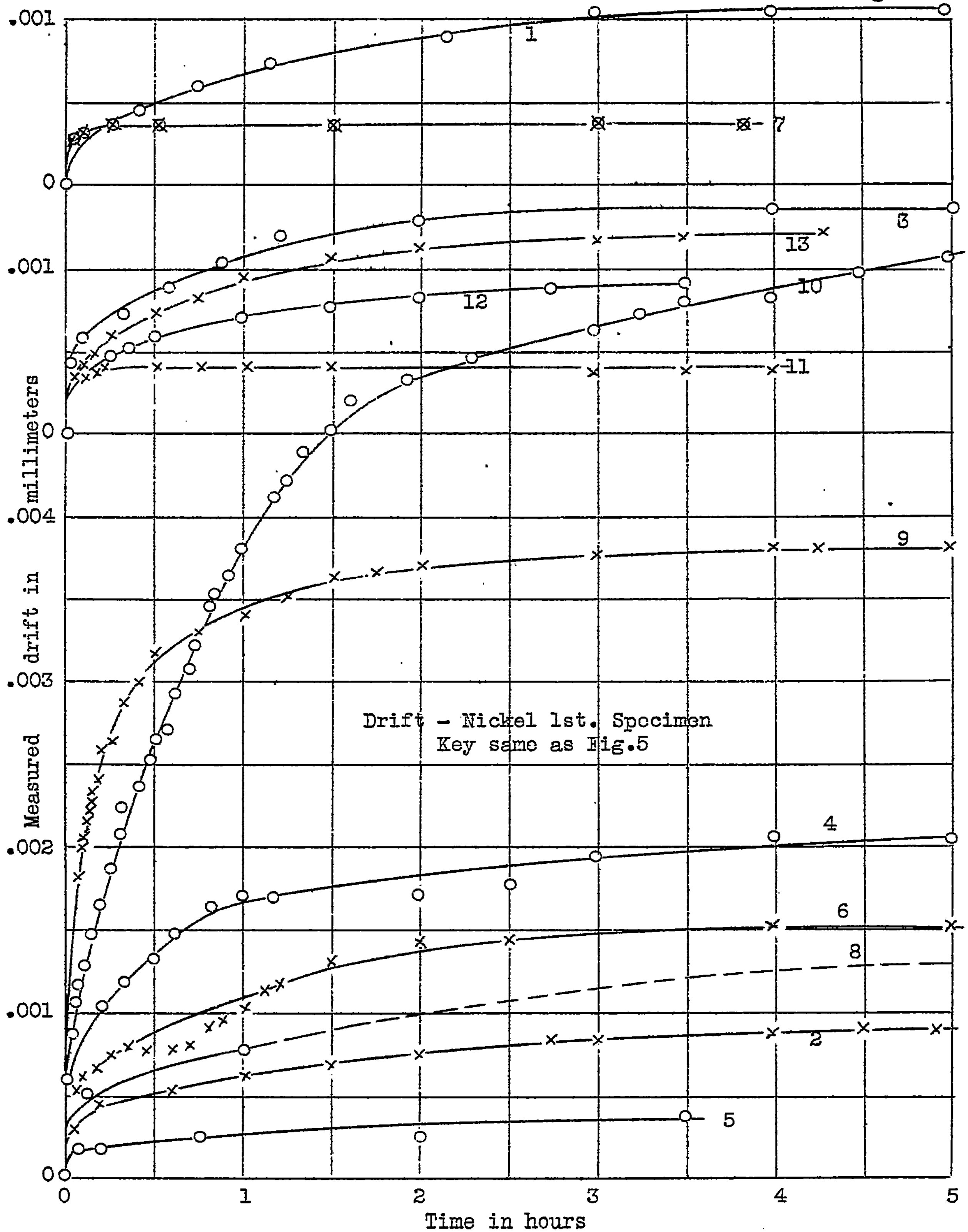


Fig.3



.001
0
.001
0
.004
.003
.002
.001
0
Measured drift in millimeters
1
7
3
13
12
10
11
9
Drift - Nickel 1st. Specimen
Key same as Fig.5
4
6
8
2
5
0
1
2
3
4
5
Time in hours

Fig.4

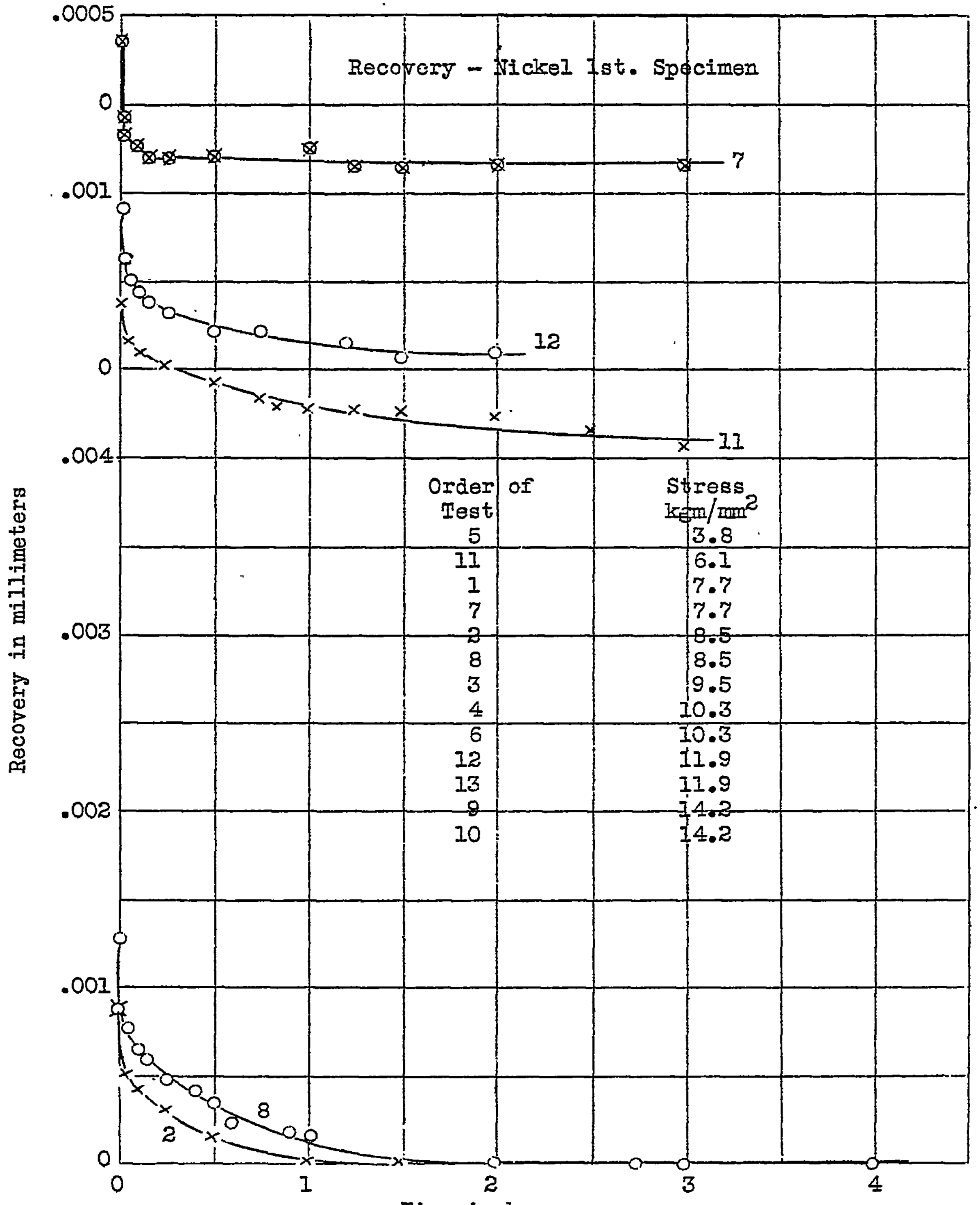
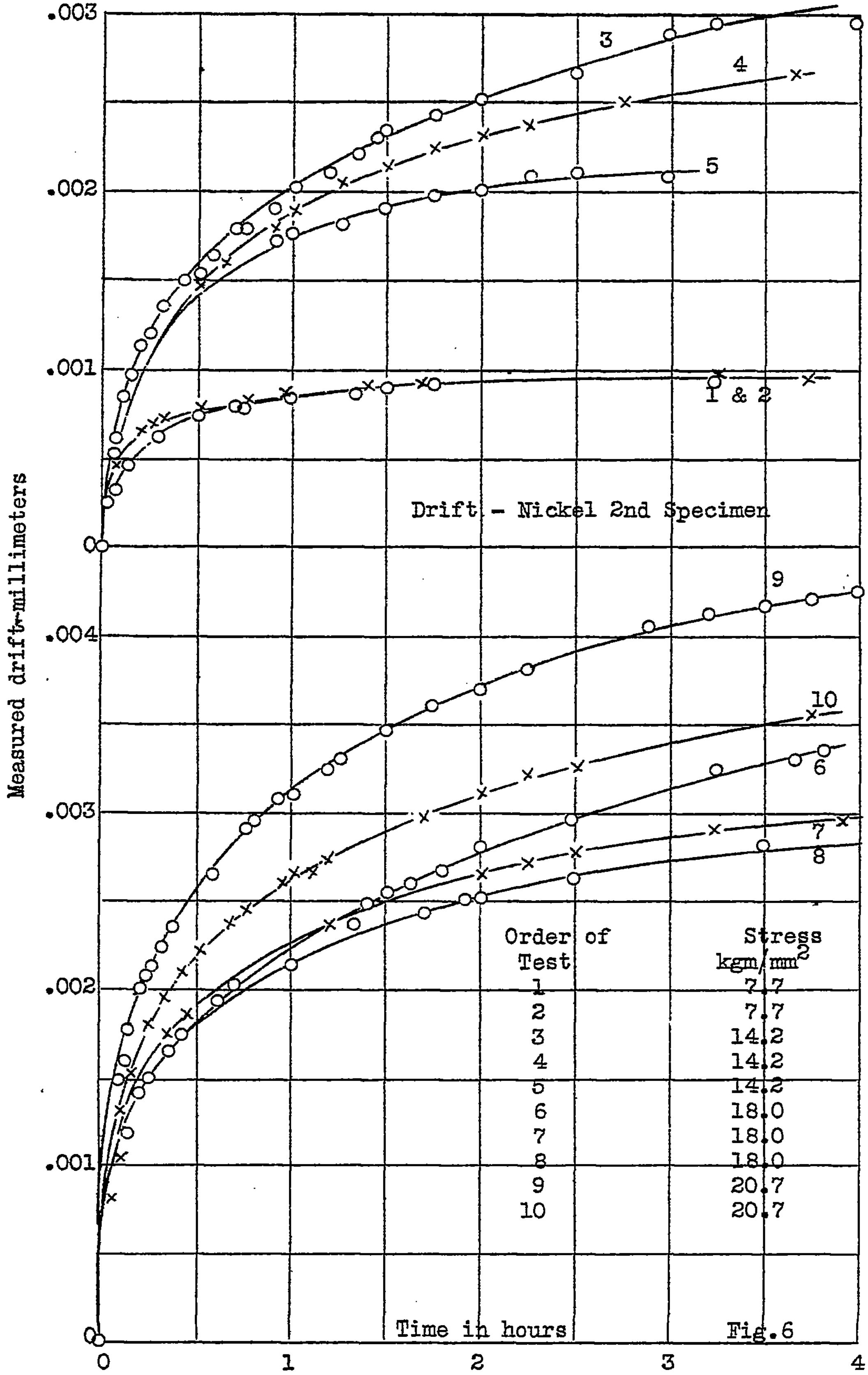

Recovery - Nickel 1st. Specimen
.0005
0
.001
0
.004
.003
.002
.001
0
Recovery in millimeters
7
12
11
8
2
Order of Test
Stress kgm/mm²
5 3.8
11 6.1
1 7.7
7 7.7
2 8.5
8 8.5
3 9.5
4 10.3
6 10.3
12 11.9
13 11.9
9 14.2
10 14.2
0
1
2
3
4
Time in hours

Fig.5



.003
.002
.001
0
.004
.003
.002
.001
0
Measured drift-millimeters
3
4
5
1 & 2
Drift - Nickel 2nd Specimen
9
10
6
7
8
Order of Test
Stress kgm/mm2
1 7.7
2 7.7
3 14.2
4 14.2
5 14.2
6 18.0
7 18.0
8 18.0
9 20.7
10 20.7
Time in hours
0
1
2
3
4

Fig.6

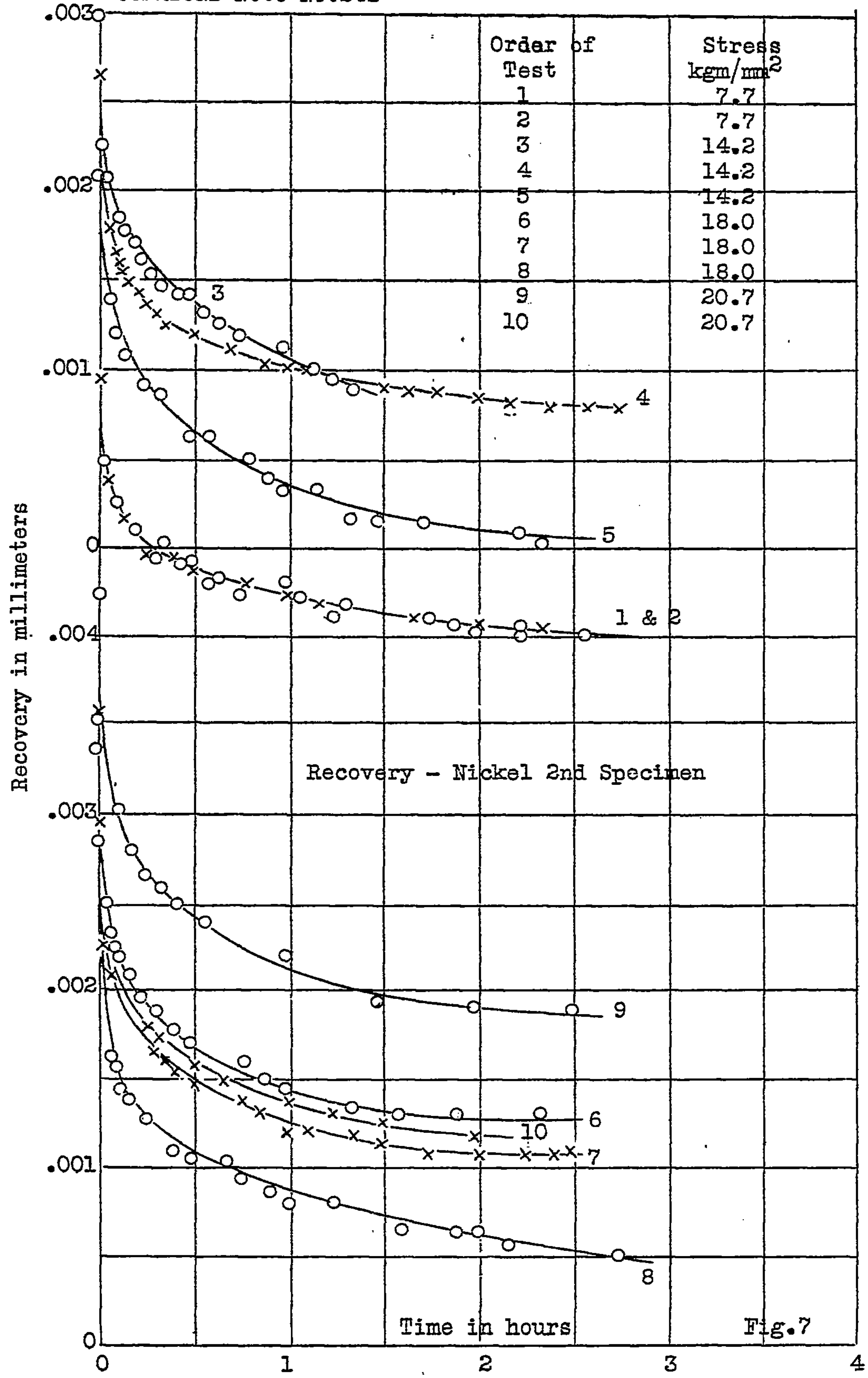

Order of Test
Stress kgm/mm²
1 7.7
2 7.7
3 14.2
4 14.2
5 14.2
6 18.0
7 18.0
8 18.0
9 20.7
10 20.7
Recovery in millimeters
.003
.002
.001
0
.004
.003
.002
.001
0
3
4
5
1 & 2
9
6
10
7
8
Recovery - Nickel 2nd Specimen
Time in hours
0
1
2
3
4

Fig.7

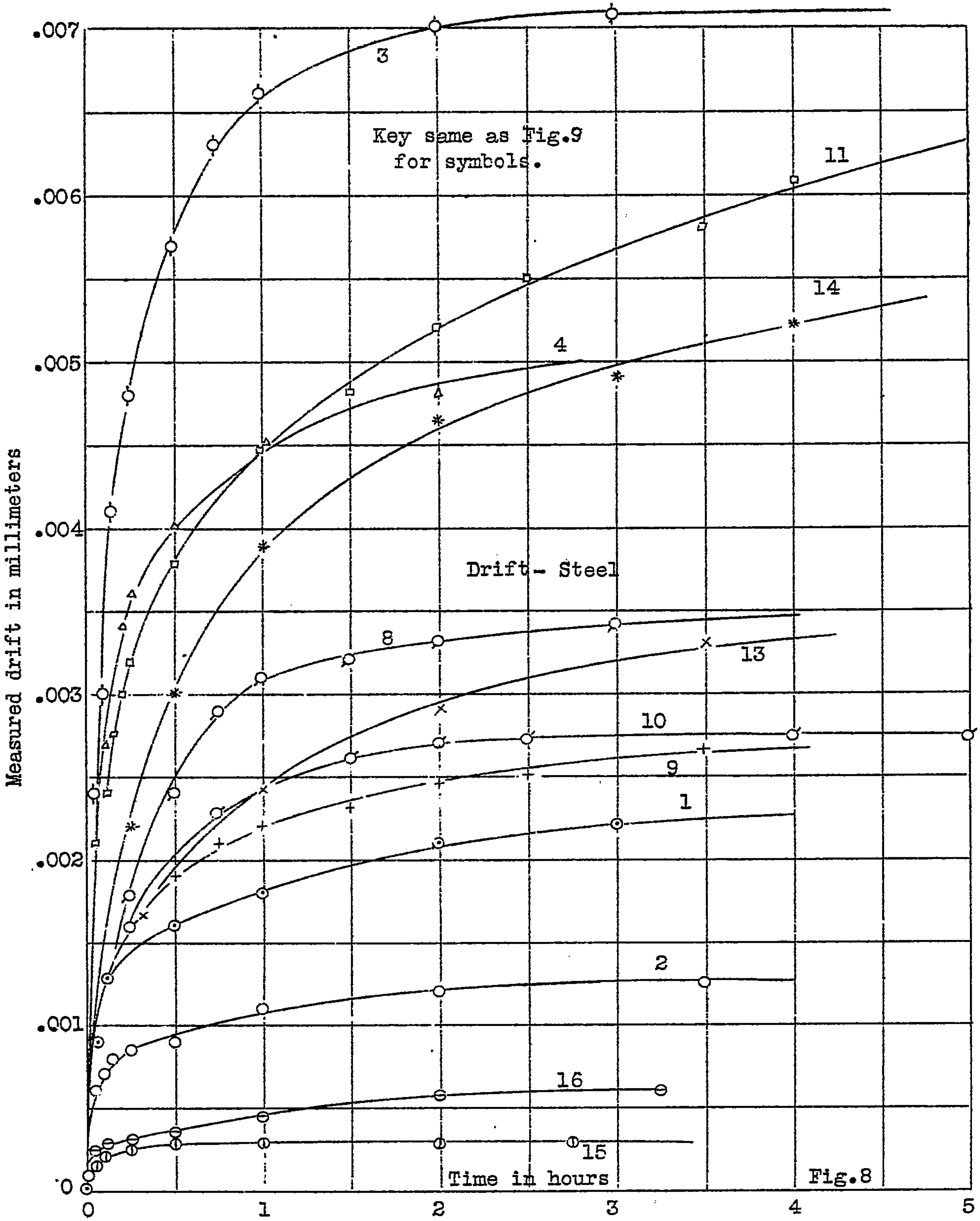
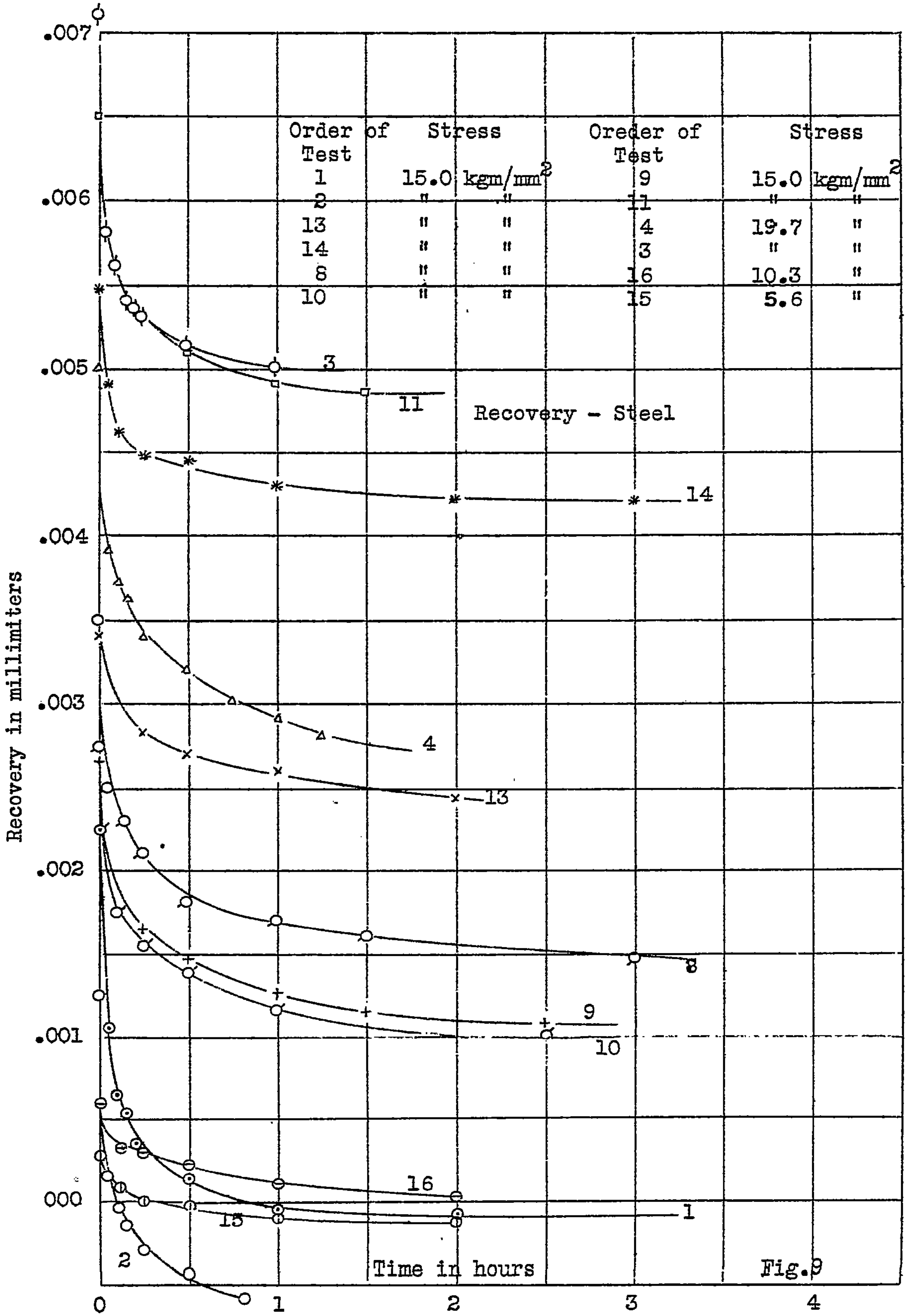

.007
.006
.005
.004
.003
.002
.001
0
Measured drift in millimeters
Key same as Fig.9
for symbols.
Drift - Steel
3
11
14
4
8
13
10
9
1
2
16
15
0
1
2
3
4
5
Time in hours

Fig.8



.007
.006
.005
.004
.003
.002
.001
000
Recovery in millimiters
Order of Test
Stress
1 15.0 kgm/mm2
2 " "
13 " "
14 " "
8 " "
10 " "
Oreder of Test
Stress
9 15.0 kgm/mm2
11 " "
4 19.7 "
3 " "
16 10.3 "
15 5.6 "
Recovery - Steel
3
11
14
4
13
8
9
10
16
1
15
2
Time in hours
0
1
2
3
4

Fig.9

Order of Test	Stress kgm/mm²
12	15.0
6	19.7
5	"
7	"

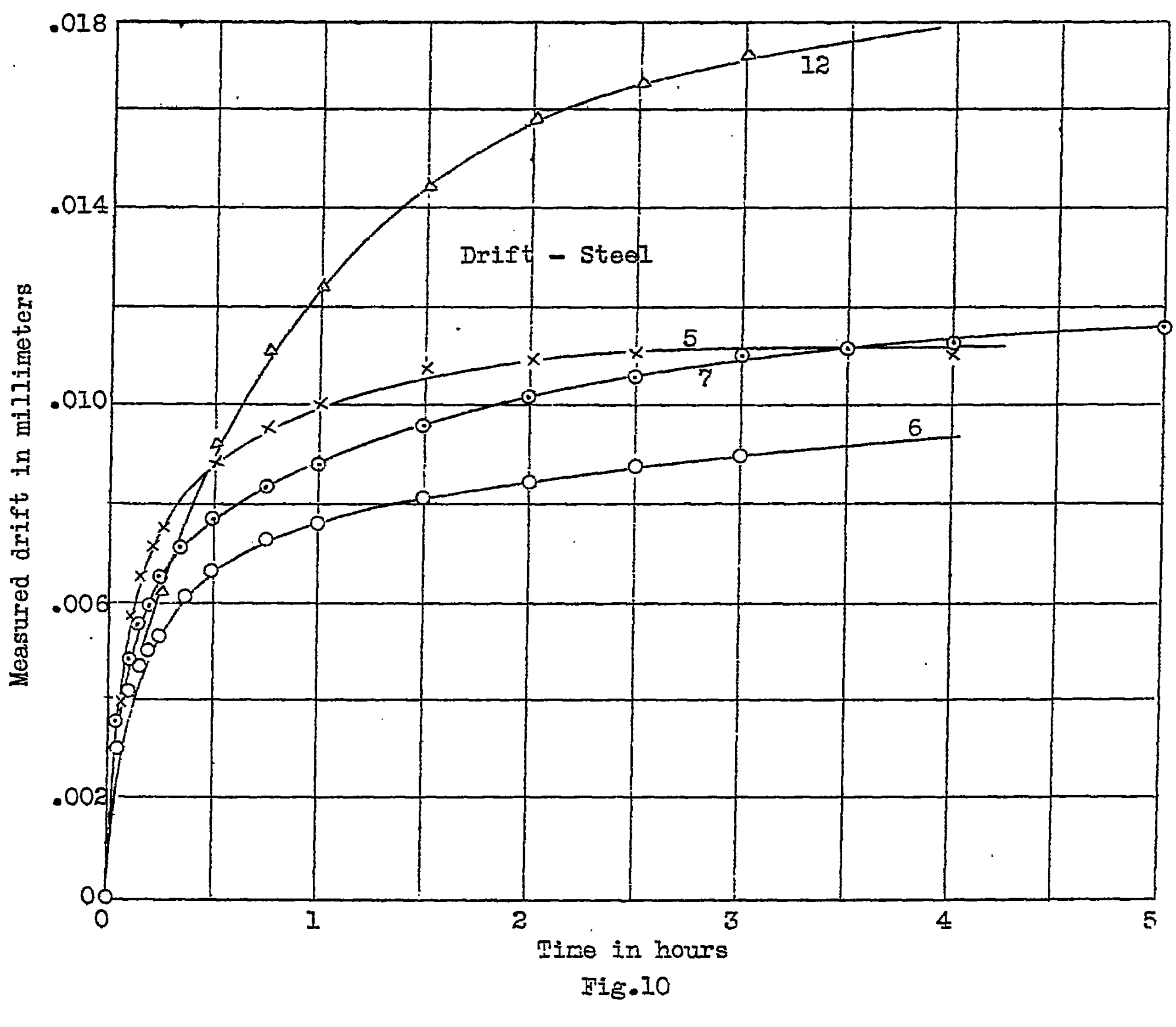


Fig.10

Order of Test	Stress kgm/mm^2
12	15.0
6	19.7
5	"
7	"

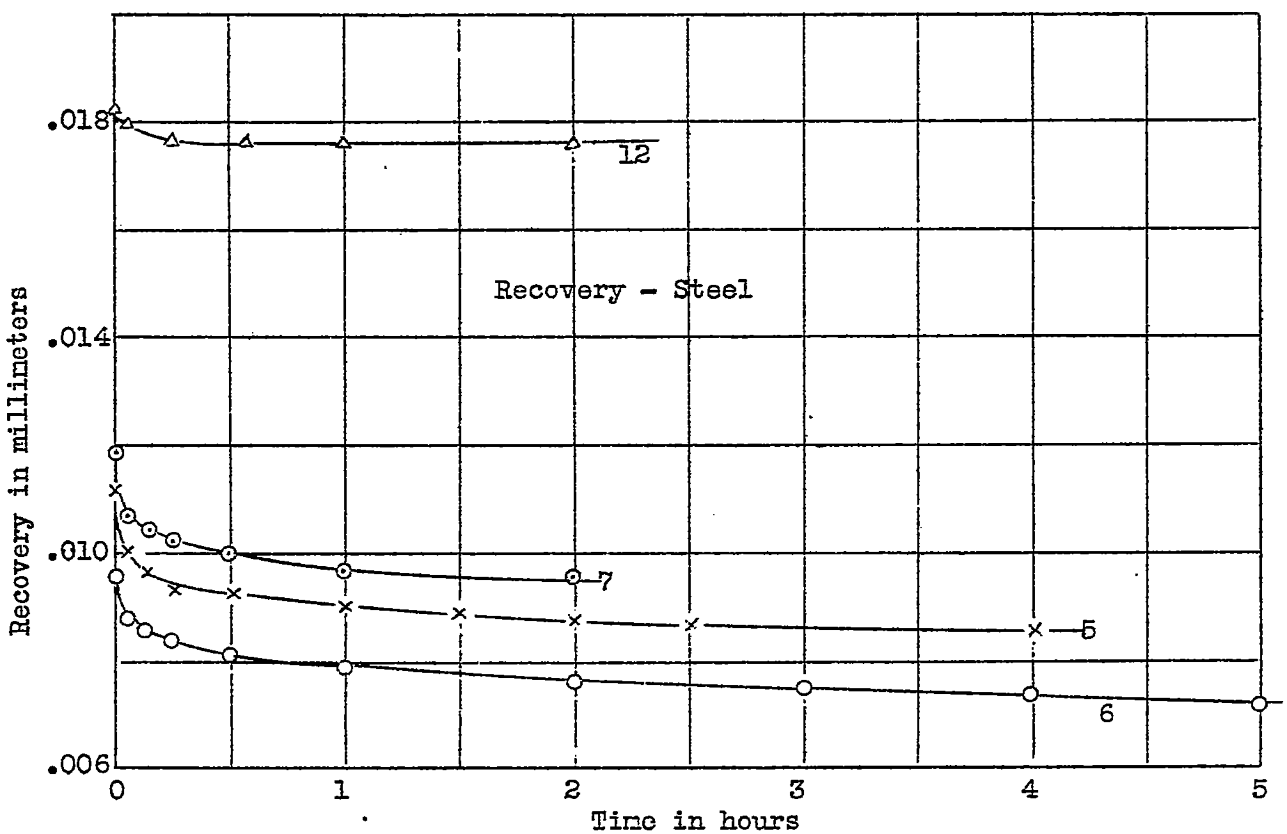


Fig.11

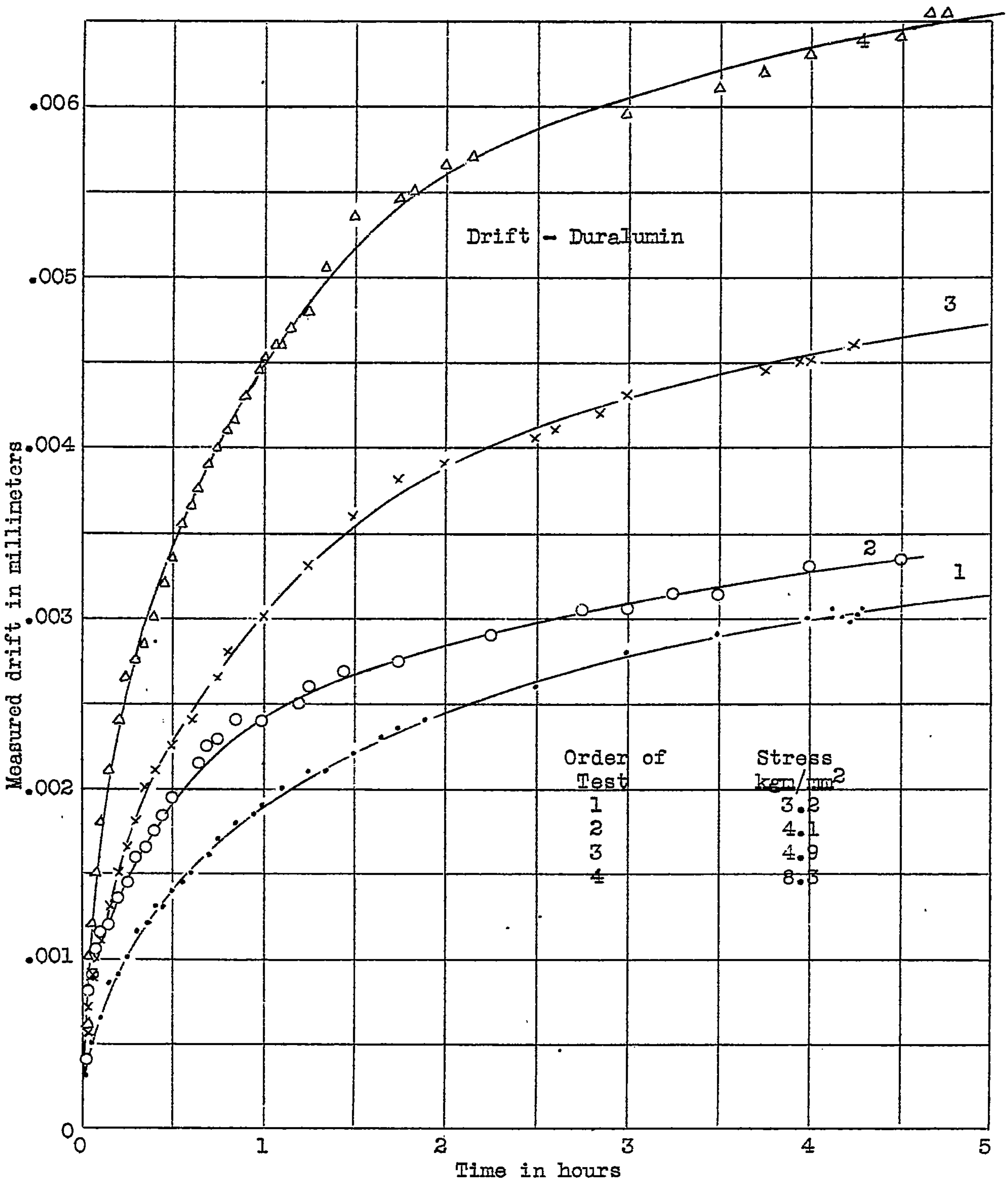

Drift - Duralumin
Measured drift in millimeters
.006
.005
.004
.003
.002
.001
0
0
1
2
3
4
5
Time in hours
1
2
3
Order of Test
1
2
3
4
Stress kgm/mm2
3.2
4.1
4.9
8.3

Fig.12

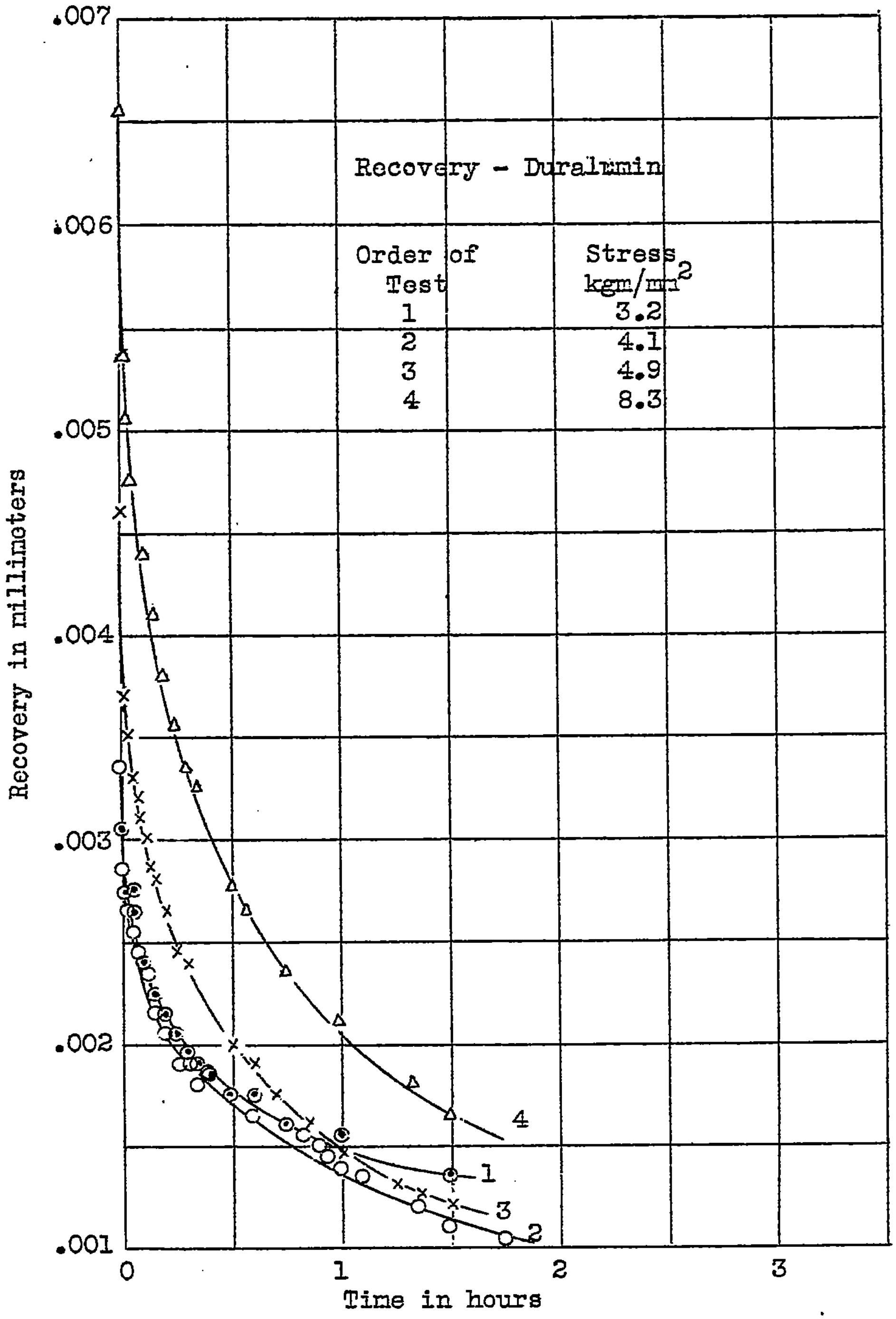
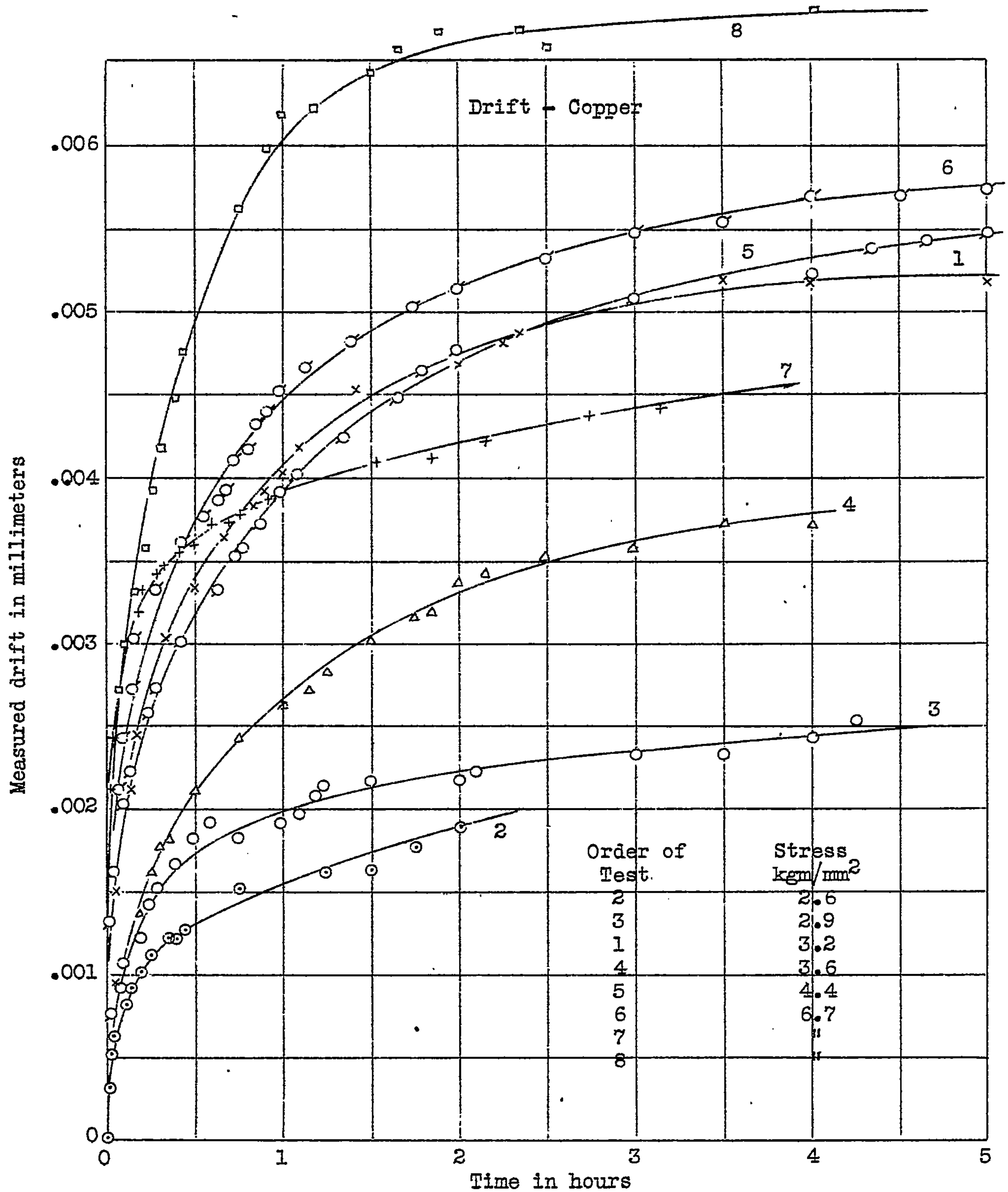

Recovery - Duralumin
Order of Test
Stress kgm/mm2
1 3.2
2 4.1
3 4.9
4 8.3
Recovery in millimeters
.007
.006
.005
.004
.003
.002
.001
0
1
2
3
Time in hours

Fig.13



8
Drift - Copper
6
5
1
7
4
3
2
.006
.005
.004
.003
.002
.001
0
Measured drift in millimeters
0
1
2
3
4
5
Time in hours
Order of Test
2
3
1
4
5
6
7
8
Stress kgm/mm2
2.6
2.9
3.2
3.6
4.4
6.7
"
"

Fig.14

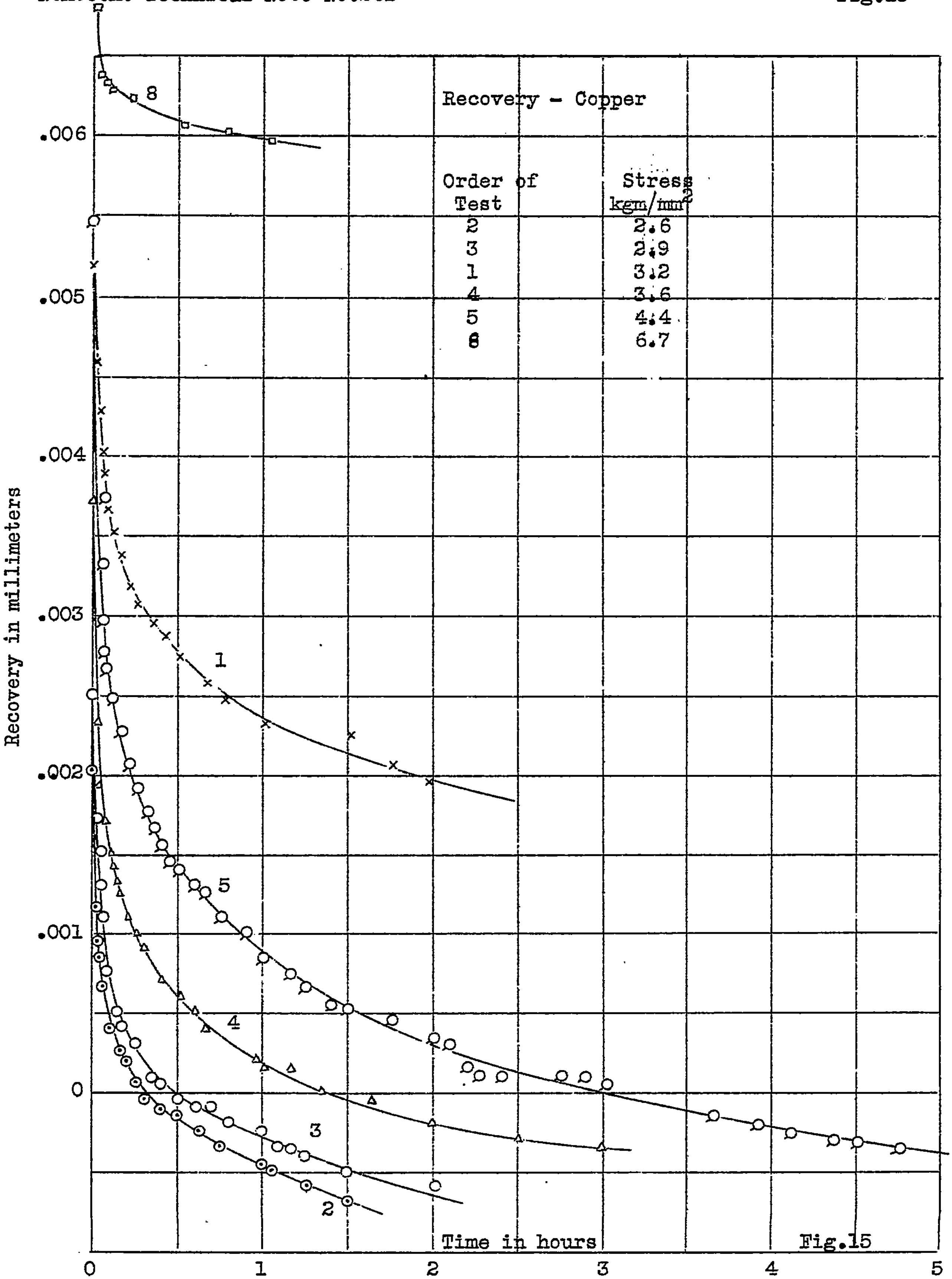

Recovery - Copper
Order of Test
Stress kgm/mm²
2 2.6
3 2.9
1 3.2
4 3.6
5 4.4
8 6.7
Recovery in millimeters
.006
.005
.004
.003
.002
.001
0
8
1
5
4
3
2
Time in hours
0
1
2
3
4
5

Fig.15

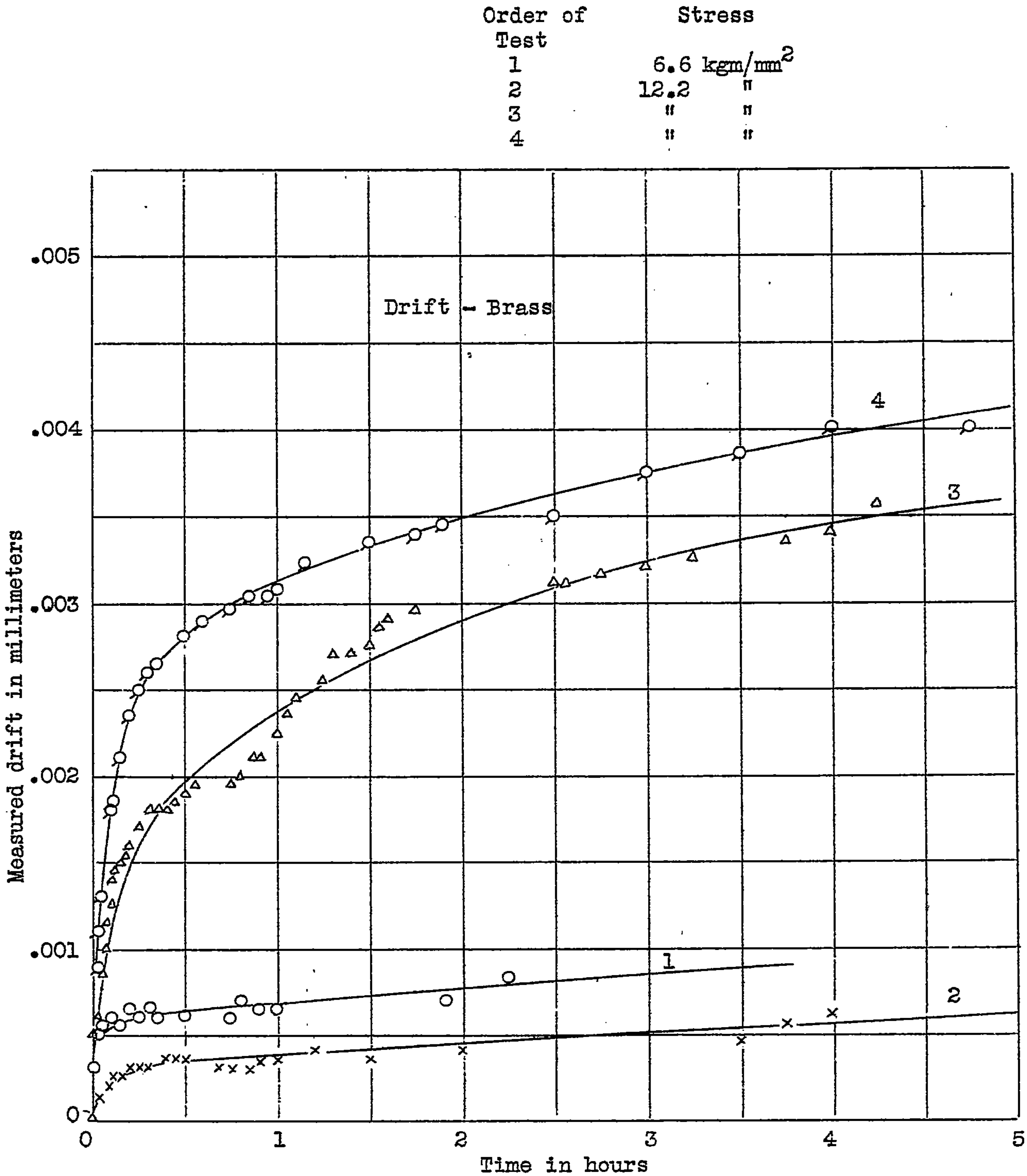

Order of Test
Stress
1 6.6 kgm/mm²
2 12.2 "
3 " "
4 " "
Drift - Brass
.005
.004
.003
.002
.001
0
Measured drift in millimeters
0
1
2
3
4
5
Time in hours
1
2
3
4

Fig.16

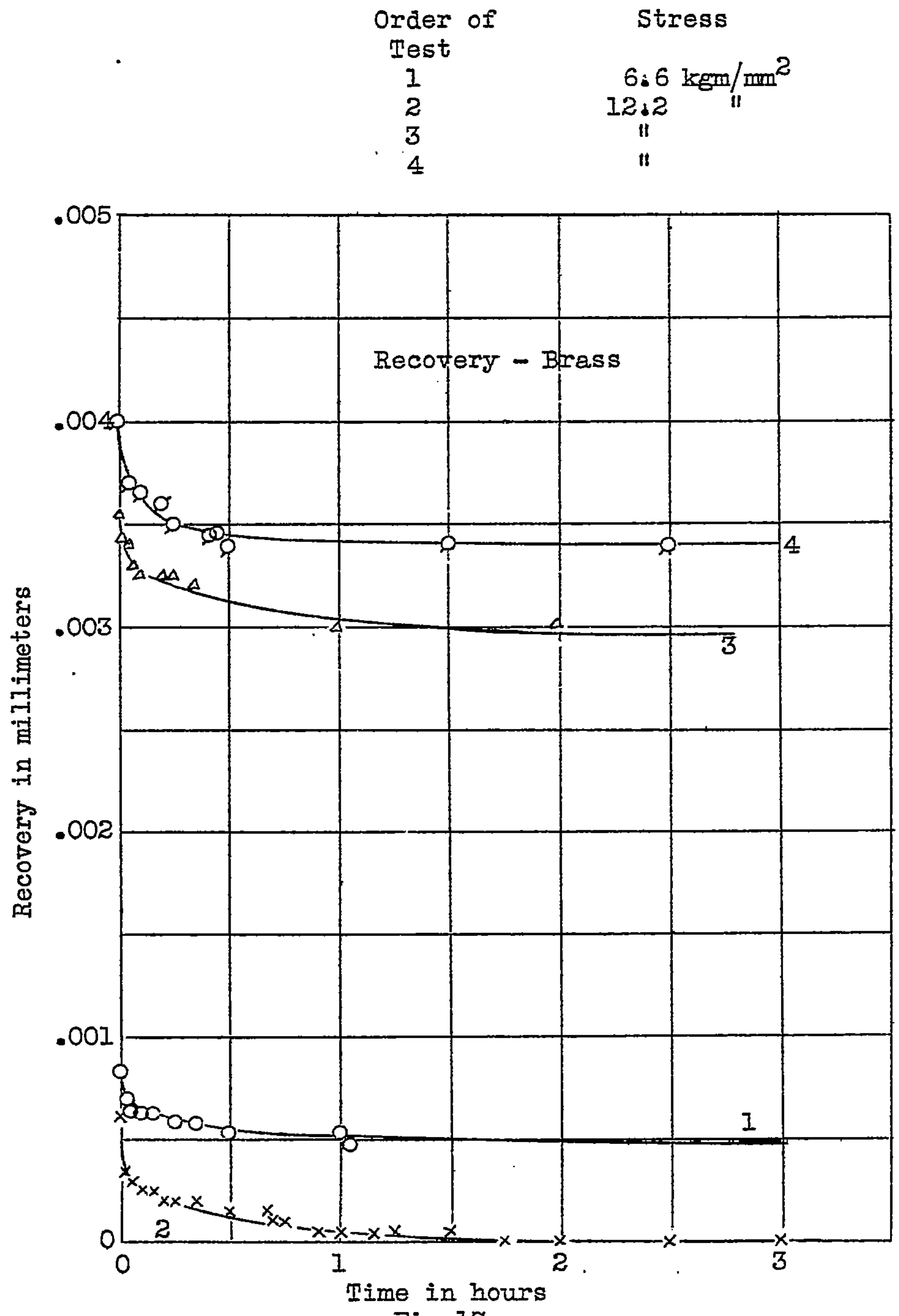

Order of Test
Stress
1
6.6 kgm/mm²
2
12.2
3
"
4
"
Recovery - Brass
Recovery in millimeters
.005
.004
.003
.002
.001
0
Time in hours
0
1
2
3
4
3
1
2

Fig.17

Order of Test	Stress kgm/mm^2
5	6.6
5	6.6
7	6.6

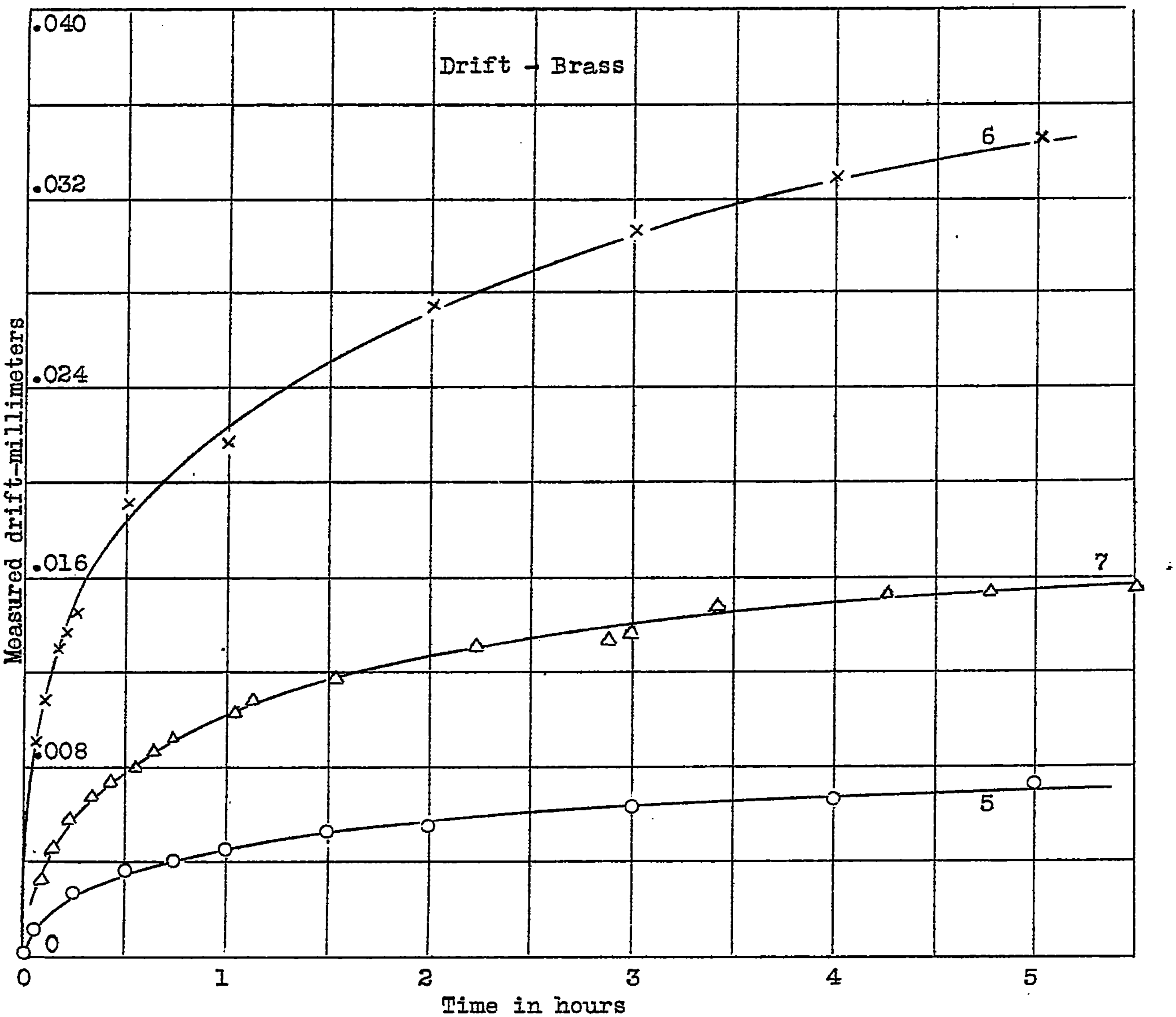


Fig.18

Order of Test	Stress kgm/mm^2
5	6.6
6	6.6
7	6.6

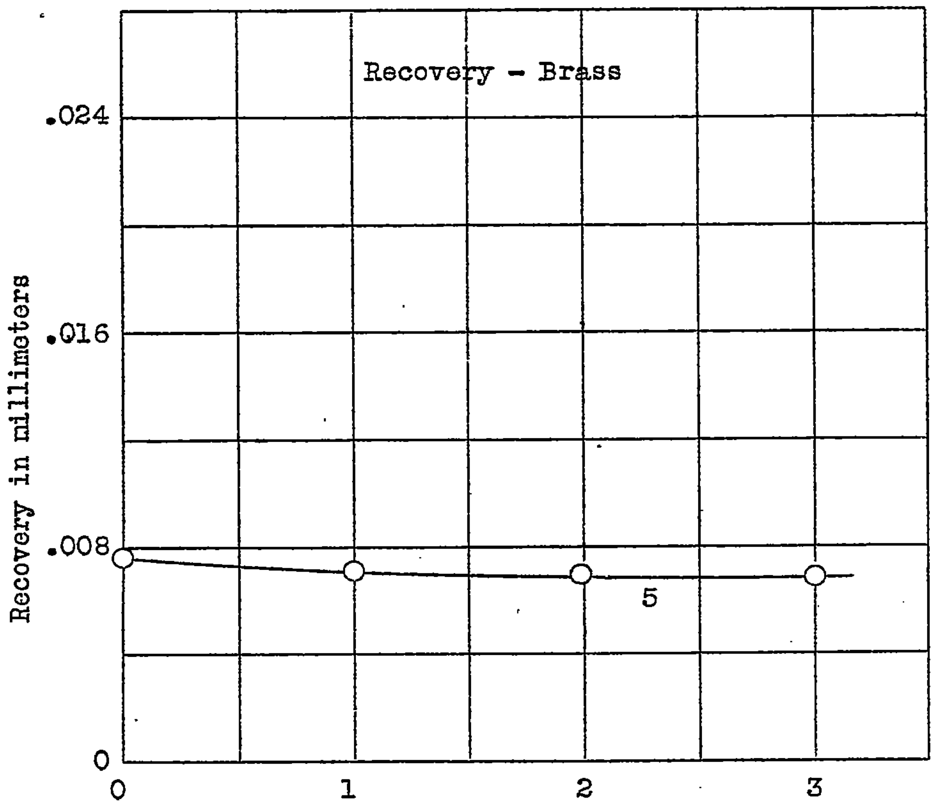
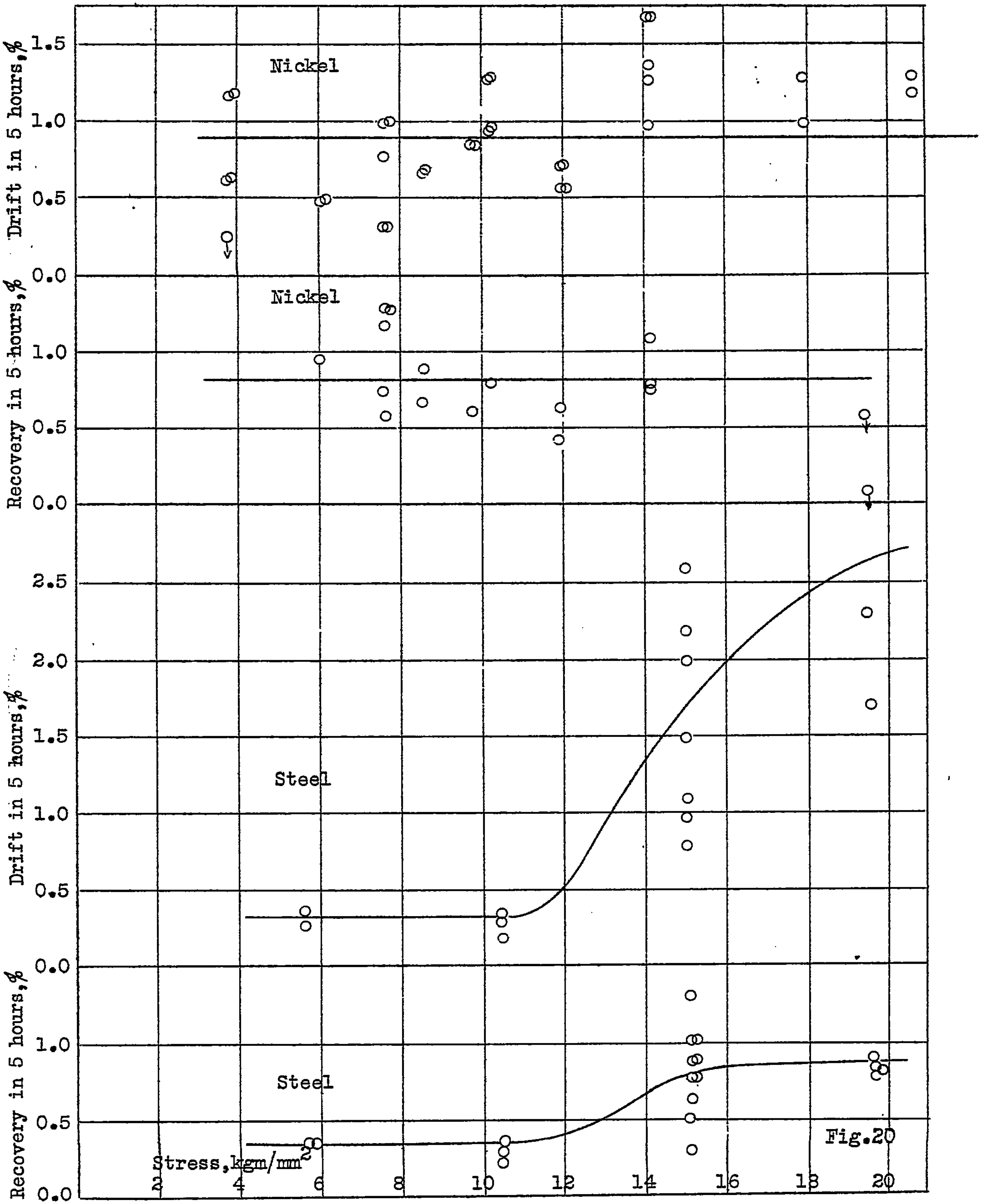


Fig.19



Nickel
Drift in 5 hours,%
1.5
1.0
0.5
0.0
Nickel
Recovery in 5 hours,%
1.0
0.5
0.0
Steel
Drift in 5 hours,%
2.5
2.0
1.5
1.0
0.5
0.0
Steel
Recovery in 5 hours,%
1.0
0.5
0.0
Stress,kgm/mm^2
2
4
6
8
10
12
14
16
18
20

Fig.20